

Mark D. Kurz

Department of Chemistry
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
U.S.A.

John J. Gurney

Department of Geochemistry
University of Capetown
Rondebosch 7700
South Africa

Helium measurements in igneous rocks and minerals have been extensively used in recent years to constrain the origin of mantle gases. Because the helium isotopic composition of a gas sample is generally a measure of the time-integrated $^3\text{He}/(^3\text{He} + ^4\text{He})$ ratio of its source, high $^3\text{He}/^4\text{He}$ ratios can be used to infer the presence of a primitive or undegassed mantle source. Extremely high $^3\text{He}/^4\text{He}$ ratios in diamonds have been reported by Ozima and coworkers (1983) that place important constraints on the origin of diamond. The highest $^3\text{He}/^4\text{He}$ ratios that they observed (up to $290 \times$ atmospheric), are significantly higher than any terrestrial igneous signature. In addition, they found a range in $^3\text{He}/^4\text{He}$ ratios of almost 10^{-4} in a suite of samples from various localities.

In an effort to understand the relationships between these data and the origin of diamond, we have performed detailed helium isotopic studies on a suite of large (1 carat) diamonds from a single kimberlite pipe (Orapa, Botswana). In order to determine the distribution of helium within the diamonds, we performed vacuum crushing experiments on a number of stones. Although significant amounts of helium are released by crushing (10^{-9} to 10^{-7} ccSTP/gram), in all cases this constituted less than 10 per cent of the total. Because crushing selectively releases gas from inclusions, we infer that most of the helium within diamond is contained by the diamond matrix.

Step heating experiments on small inclusion-free fragments indicate that individual diamonds contain dramatic internal variability with respect to $^3\text{He}/^4\text{He}$. The experiments were performed by heating the diamonds in two carefully controlled temperature steps (at 2000°C). In the first step, the diamonds are partially graphitized, and the helium released has quite low $^3\text{He}/^4\text{He}$ ratios (.05 to 3 times atmospheric). In the second step, the diamonds are completely graphitized, and extremely high $^3\text{He}/^4\text{He}$ ratios are observed (30 to 80 times atmospheric). The $^3\text{He}/^4\text{He}$ ratio released by this procedure can differ by up to a factor of 100 within a single diamond. We interpret these results to indicate that helium is zoned within the diamonds. The first graphitization step selectively releases the helium associated with defects, because graphitization begins at defects within the diamond. The later graphitization step releases helium from relatively defect free zones in the diamond. This explanation is supported by preliminary dissection experiments on single stones.

This behavior is observed in diamonds that contain peridotitic and eclogitic mineral inclusions, and the helium data does not at present differ between these two types. There appears to be some correlation to crystal form in that polycrystalline aggregates display lower $^3\text{He}/^4\text{He}$ ratios than the octahedral growth forms.

Although the recent discovery of cosmogenic helium in rocks (Kurz, 1986) provides a new mechanism for generating high $^3\text{He}/^4\text{He}$ ratios, this does not appear to be relevant to the present samples due to the depth of the kimberlite pipe. However, preliminary calculations suggest that the high $^3\text{He}/^4\text{He}$ ratios could be produced by $^6\text{Li}(n, \alpha)^3\text{He}$ within the mantle source, if Li contents are several ppm and the source region is enriched in Th and U.

The large helium isotopic variability within single diamonds has important implications. First, it suggests that much of the isotopic variability is caused by ingrowth of radiogenic ^4He , and that Th and U are zoned within single diamonds. Therefore, helium may possibly be used to date individual diamonds. In addition, if the explanation for the heterogeneity given here is correct, the highest $^3\text{He}/^4\text{He}$ ratios may be found in those diamonds with the fewest defects.

REFERENCES

- OZIMA M., ZASHU O. AND NITOH O. 1983. $^3\text{He}/^4\text{He}$ ratio, noble gas abundance and K-Ar dating of diamonds. *Geochimica et Cosmochimica Acta* 47, 2217-2224.
- KURZ, M. D. 1986. Cosmogenic helium in a terrestrial igneous rock. *Nature* 320, 435-439.